**Growing willow biomass crops for bioproducts and bioenergy in the Northeastern and Midwestern United States**

E.H. White[1]*, T.A. Volk[1], A.J. Stipanovic[1], T.E. Amidon[1], E. Neuhauser[2], L.P. Abrahamson[1], E. Gray[3], C. Lindsey[3], J. Jarnefeld[4], D.J. Aneshansley[5], R.C Fillhart[1], B.D. Kiernan[1] and S. Edick[6]
[1] State University of New York College of Environmental Science and Forestry
133 Illick Hall, Syracuse, NY, USA, 13210 (tavolk@mailbox.syr.edu, fax: 315-47-6934))
[2] Niagara Mohawk Power Corporation, Syracuse, NY, [3]Antares Group, Landover MD,
[4] New York State Research and Development Authority, Albany, NY, [5] Dept. of Agricultural and Biological Engineering, Cornell University, Ithaca, NY, [6]South Central NY RC&D, Norwich, NY

Cultivation of willow in the Northeastern and Midwestern United States began in the 1840s by immigrants in western New York and Pennsylvania. By the late 1800s cultivation of willows for basketry and furniture had spread from the shores of Maryland to the western borders of Wisconsin and Illinois. By the early 1900s, New York State dominated willow cultivation in the United States, with 60% of the total reported area, and about 45% of the income generated from willow products. However, as the demand for willow baskets dropped off rapidly in the 1920s and 1930s, only pockets of willow cultivation remained.

The cultivation of willow was revitalized in upstate New York in the mid 1980s at the State University of New York College of Environmental Science and Forestry (SUNY-ESF). The focus was research on the production of willow as a locally produced, renewable, cellulose feedstock for bioenergy and bioproducts. Over 20 organizations have teamed up to form the Salix Consortium, whose goal is to facilitate the commercialization of willow and poplar biomass crops in the Northeastern and Midwestern regions of the United States. In 1995, the Salix Consortium was one of three competitively bid national projects selected to develop a dedicated feedstock energy project under the Biomass Power for Rural Development Program supported by the United States Departments of Energy and Agriculture. To reach these goals a series of simultaneous activities, including research, regional clone-site trials, a large-scale demonstration program, and outreach and education efforts, were initiated (Figure 1).

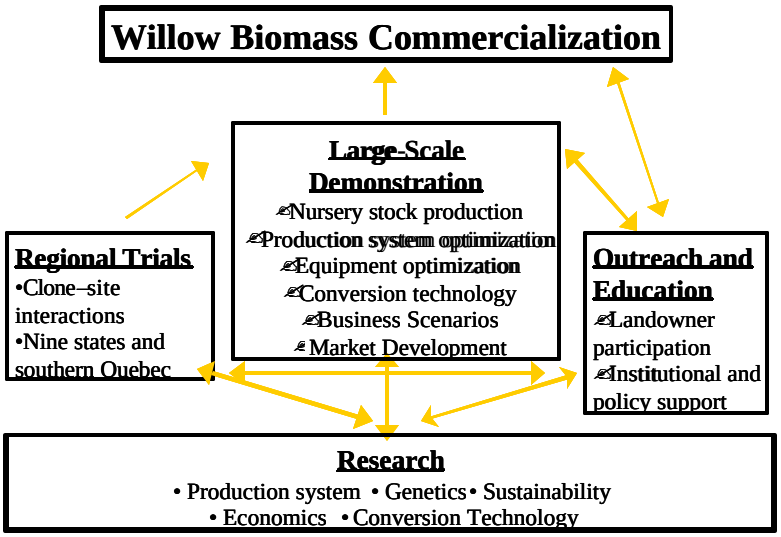


**Figure 1.** Components of the Salix Consortium's program that are being implemented simultaneously to reach the goal of commercialization.

Willow biomass cropping systems can also produce valuable environmental and social benefits. These include reduced $SO_2$ and $NO_x$ power plant emissions when used as a fuel for co-firing with coal, no net addition of $CO_2$ to the atmosphere when used to generate electricity, sequestration of carbon in soil,

reduced soil erosion and non-point source pollution from agricultural land, and enhanced agricultural landscape diversity. Willow biomass, as an alternative agricultural crop, has the potential to play a crucial role in revitalizing the economy of rural communities. The production, quantification, and valuation of these benefits are essential in order to make the system economically viable under the current bioproducts and bioenergy industry structure.

Between 1998 and 2000 over 280 ha of willow biomass crops were established in western and central New York. Smaller trials have been established in nine states and southern Quebec. First rotation yields of the best clone in the trials that have been harvested to date has ranged from 8.4 odt/ha/yr in Burlington, VT to 9.2 odt/ha/yr in Massena, NY. Second rotation yields have increased by 20 to 115%, depending on the site. Correlation of these research plot yields with commercial harvests will begin in the winter of 2001/2002 with the large-scale harvest of the first 40 ha. The biomass will be co-fired with coal at the NRG Dunkirk power plant in western New York, used for gasification tests, and for research on the fabrication of new biobased materials and chemicals as alternatives to products currently derived from non-renewable fossil fuels.

In addition to co-firing and gasification for energy production, willow biomass represents a relatively low cost and locally available feedstock for the production of liquid fuels, chemicals and advanced materials derived from its lignin, cellulose and hemicellulose. Our analysis has shown that willow wood derived from three-year old stems is only 19% lignin compared to 22-30% for mature hardwoods, which will facilitate the pulping process while enhancing the overall product yield for those chemicals derived from the polysaccharide fraction of willow (glucose, ethanol, furfural, levulinic acid, etc.). The dry weight ratio of cellulose to xylan hemicellulose in willow was found to be approximately 3.5 to 1 based on a new Nuclear Magnetic Resonance (NMR) technique. This ratio is higher than typically observed in most hardwood species.

Studies are in progress utilizing a fungal pre-treatment (biopulping) to optimize the yield of both usable papermaking fiber (cellulose) and water-extractable xylan from willow. Trials at the Empire State Paper Research Institute (ESPRI) at SUNY - ESF have revealed that willow fiber can make paper of equivalent strength and quality to eucalyptus, a "standard" papermaking pulp worldwide, and represents a viable commercial fiber resource. In addition, we have been successful in generating aqueous liquid crystalline phases of extracted xylan, which we plan to fabricate into high performance, biodegradable fibers and films as well as composites with thermoplastic bacterial polyesters. These products represent biodegradable alternatives to petroleum-derived polyethylene and polystyrene. Other "high tech" applications of willow biomass include stimuli responsive elastomers, which could be used in shock absorbers, as equipment dampeners, artificial muscles, biomedical equipment, etc., and in the development of micron-sized dispensers for insect pheromones used to control forest and agricultural pests. From an economic perspective, we have estimated that process improvements leading to efficient xylan (hemicellulose) extraction and utilization have the potential to significantly improve the value of a ton of willow biomass. About 125 kg of xylan (assuming 25 wt% xylan and 50% recovery) could be recovered from each tonne of willow biomass. This would add $20 to the value of a ton of willow biomass.

The ongoing research and large-scale demonstration of willow biomass crops, supported by the DOE, USDA and NYSERDA; developments in the extraction and use of xylan from willow biomass; and the active participation of Consortium partners are creating new opportunities to reach the goal of commercialization of the system. The development of a vibrant willow biomass enterprise can play an important role in bolstering the region's farm and forestry sectors, increasing energy independence, strengthening the protection of the environment, and mitigating pollution problems.